THE UNIVERSITY OF ALBERTA

THE ATTEMPTED INTRAMOLECULAR TRAPPING OF A 1,3-DIRADICAL

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled THE ATTEMPTED INTRAMOLECULAR TRAPPING OF A 1,3-DIRADICAL, submitted by Gary W. Gibler in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

Evidence of several different types has suggested that the gas-phase thermal decomposition of the 1-pyrazoline system proceeds by simultaneous cleavage of the two C—N bonds and N_2 elimination in the initial, rate-determining step to give a trimethylene intermediate. The evidence includes conclusions based on thermodynamic parameters obtained from kinetic studies and on secondary deuterium isotope effects. Theoretical calculations based on trimethylene have contributed an explanation of the stereochemical observations.

The intermediate is known to be a very transient species, but the theoretical studies indicate that it should be capable of concerted thermal addition to an olefinic bond.

3-(5'-Hexenyl)-1-pyrazoline was synthesized and was subjected to pyrolysis to test the hypothesis that the intramolecular olefinic bond would serve as an effective trap for the diradical intermediate. Analysis of the products showed that the trapping was not successful. Trapping products were not formed in detectable amount.

It was concluded that the $\Delta G^{\ddagger}$ for the trapping of the intermediate is more than 8.2 kcal $mole^{-1}$ higher than the $\Delta G^{\ddagger}$ for closure of trimethylene to cyclopro-

pane, or at least 15 kcal $mole^{-1}$.

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HISTORICAL

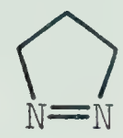
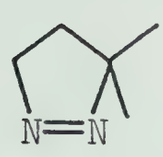
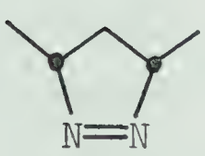
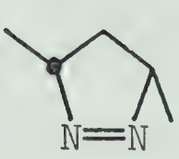
Several investigations have been made into the mechanism of the gas-phase thermolysis of 1-pyrazoline and its derivatives. A great deal of evidence has been accumulated by Crawford and co-workers to indicate that the pyrolysis of alkyl derivatives of 1-pyrazoline proceeds via simultaneous homolytic cleavage of the two C—N bonds to give a nitrogen-free trimethylene intermediate.

Mishra (1) synthesized a series of methyl-substituted pyrazolines for thermolysis. The kinetic parameters (Table I) show that successive methyl group substitutions on C_3 or C_5 of 1-pyrazoline bring about a decrease in activation energy of 1.2 ± 0.2 kcal $mole^{-1}$ per methyl. Thus the activation energies of 5, 6, and 7 are smaller than that of 2, while a further successive reduction is observed for 8 and 9. It was suggested by the authors that these data indicate that both C—N bonds are being cleaved simultaneously in the rate-determining transition state.

A one-bond cleavage mechanism, heterolytic or homolytic, can be shown to be inconsistent with the data. A mechanism involving heterolytic cleavage and a dipolar transition state cannot explain the observed

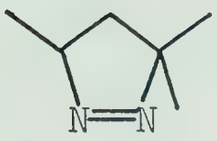
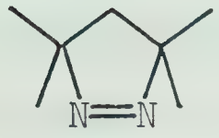
Table I

Kinetic parameters from the thermolysis of 1-pyrazolines

Compound	Ea (kcal mole^{-1})	Log A	ΔS^*_{250} (eu)
1 	42.4 ± 0.3	15.93 ± 0.13	11.2 ± 0.6
2 	41.0 ± 0.3	15.70 ± 0.15	10.1 ± 0.7
3 	42.2 ± 0.2	15.85 ± 0.05	10.8 ± 0.3
4 	42.8 ± 0.2	14.10 ± 0.07	2.9 ± 0.3
5 	40.0 ± 0.2	15.85 ± 0.03	10.8 ± 0.2
6 	40.3 ± 0.3	15.54 ± 0.11	9.4 ± 0.5
7 	40.2 ± 0.3	15.67 ± 0.11	10.0 ± 0.5

(cont'd.)

Table I (cont'd.)

8 	39.0 ± 0.4	15.42 ± 0.21	8.4 ± 0.9
9 	37.7 ± 0.4	14.49 ± 0.12	4.6 ± 0.8

decrease in activation energy on alkyl substitution at C_3 and C_5. For example, 5 and 8 would be expected to show similar activation energies, and in fact the overall order of reactivity in Table I is the reverse of that expected for a dipolar transition state. A homolytic one-bond cleavage mechanism can be rejected since, for example, 5 and 9 would be expected to show similar activation energies with the pre-exponential factor differing only by a factor of two.

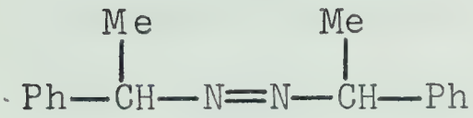
Further evidence against the homolytic one-bond cleavage mechanism is the observation during a control run that cis- and trans-3,5-dimethyl-1-pyrazoline were not interconverted. That is, apparently nitrogen is eliminated in the rate-determining step, and the intermediate is a hydrocarbon species.

A great deal of information about reaction mechanisms has been made available by the study of secon-

dary deuterium kinetic isotope effects. Consider an H—C—X group in which the C—X bond is undergoing stretching as the molecule moves along the reaction coordinate and is breaking at the rate-determining transition state. The α-hydrogen bending force constant changes as the C—X stretching force constant changes, and this leads to a measurable change in rate on substitution of a deuterium atom for an α-hydrogen.

A calculated value of kinetic isotope effect may be obtained, based on the geometry of the molecule and the values of the force constants and the atomic masses in the reactant state and the estimated values of quantities which are changed in the transition state (2).

Seltzer and co-workers (3) have gathered experimental data on the rates of thermolysis of various azo compounds, which may be correlated with calculated isotope effects, and have shown that at a site that is changing hybridization from sp^3 in the ground state to sp^2 in the transition state, each α-deuterium substitution leads, at 105°, to a 12-14% decrease in the rate of reaction. Thus a comparison (3a) of azo-bis-α-phenylethane (10) with azo-bis-α-phenylethane-α,α'-d_2 (11) showed an isotope effect $k_{10}/k_{11} = 1.27 \pm 0.03$ at 105.28°. It was suggested that the isotope effect is



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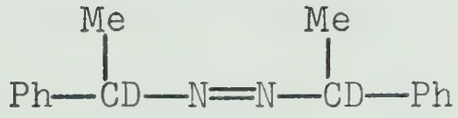

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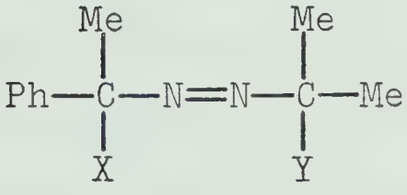
evidence that both C—N bonds are being broken simultaneously in the slow step of the reaction.

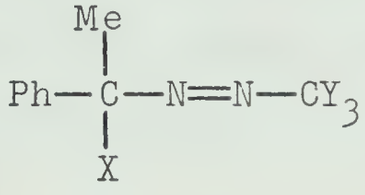
The study of less symmetric compounds provided further insight. The following compounds were synthesized:



12 X = Y = H

13 X = D, Y = H

14 X = H, Y = D



15 X = Y = H

16 X + D, Y = H

17 X = H, Y = D

In the study of the α-phenylethylazo-2-propane series, the observed isotope effects were k_{12}/k_{13} = 1.16, k_{12}/k_{14} = 1.04. This was taken as an indication that the bond-breaking is asymmetric; that is, while both bonds are undergoing breakage in the transition state, the cleavage of the phenylethyl group is much more advanced than the cleavage of the iso-propyl group. The α-phenylethylazomethane case proved to be at the other extreme relative to azo-bis-α-phenylethane.

The observed isotope effects, $k_{15}/k_{16} = 1.13$, $k_{15}/k_{17} = 0.94$, led to the conclusion that the phenylethyl group breaks away in the rate-determining step while the methyl group undergoes breakage in a second step.

Halevi has reviewed secondary kinetic isotope effects (4), and has shown by means of the equation

$$n\delta\Delta G^{\ddagger} = RT\ln k_H/k_D,$$

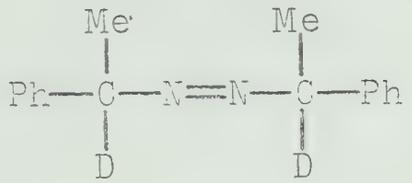
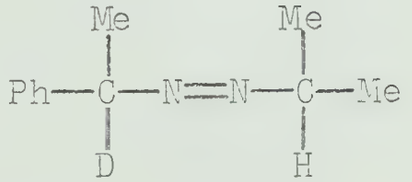
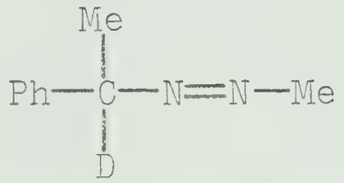
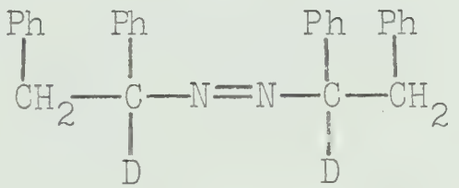
where n is the number of deuterium atoms on the carbon undergoing[a] change of hybridization and $\delta\Delta G^{\ddagger}$ is the free energy change per isotopic substitution, that α-deuterium kinetic effects commonly show $\delta\Delta G^{\ddagger}$ values in the range 80-115 cal mole^{-1}.

The work of Seltzer yields the following values of $\delta\Delta G^{\ddagger}$: for 11, 89 ± 6; for 13, 114 ± 10; and for 16, 105 ± 8 cal mole^{-1}. These values fit comfortably within the stated range and provide clearer evidence of bond-breaking in the transition state than the rate-constant ratios, since the $\delta\Delta G^{\ddagger}$ values are temperature-independent. Some data, including rate constant ratios and $\delta\Delta G^{\ddagger}$ values, found in recent reports of investigations of azo compound decompositions are listed in Table II.

Crawford and co-workers have studied the rates of decomposition of several deuterated 1-pyrazolines in

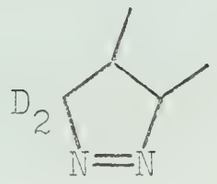
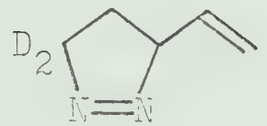
Table II

Isotope effects observed in the decomposition of some azo compounds

Thermolysis of	Solvent	T	kH/kD	$\delta\Delta G^{\neq}$ (cal)	Reference
11 	ethylbenzene	105.3°	1.27	89 ± 6	3
13 	diphenylether-benzoquinone	143.2°	1.148	114 ± 10	3
16 	diphenylether-benzoquinone	161.0°	1.13	105 ± 8	3
 meso-,	ethylbenzene	106.47°	1.221	75 ± 10	5
racemic,	ethylbenzene	106.45°	1.202	69 ± 10	5

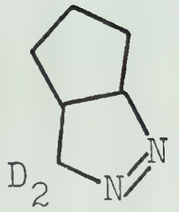
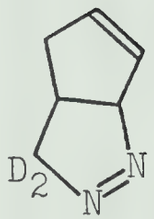
(cont'd.)

Table II (cont'd.)

18		gas phase	229.4°	1.19	86	6
19		gas phase	229.4°	1.40	84	6
						
20	<u>cis</u>-	gas phase	220.9°	1.19	86	7
21	<u>trans</u>-	gas phase	220.9°	1.21	93	7
23		gas phase	134.5°	1.21	77	8

(cont'd.)

Table II (cont'd.)

	gas phase	219.9°	1.21	93	10
	gas phase	155.3°	1.23	83	10

order to determine the magnitude of the kinetic isotope effect. The results have supplemented very well the conclusions derived from the kinetic parameters observed for the methylated series. Although the progressive decrease in activation energy on going through the series from 1 to 9 was suggested to be evidence for simultaneous two-bond cleavage, it was noted (6) that it is also possible that the progressive increase in rate could arise from an increase in ground-state energy due to such conformational effects as 1,3-diaxial interactions, which are relieved in the transition state by the cleavage of one bond. The study of deuterium-substituted derivatives avoids this question by providing a predictable isotope effect without introducing complications due to conformational effects.

Deuterated pyrazolines synthesized for study include 1-pyrazoline-3,3-d_2 (18), 1-pyrazoline-3,3,5,5-d_4 (19) (6), cis-3,4-dimethyl-1-pyrazoline-5,5-d_2 (20), and trans-3,4-dimethyl-1-pyrazoline-5,5-d_2 (21) (7). The observed relative rates and the $\delta\Delta G^{\ddagger}$ values (Table II) support the simultaneous two-bond cleavage mechanism.

Further important evidence for simultaneous cleavage of the two C—N bonds in pyrazolines has been provided by Cameron (8) in his study of the thermolysis of 3-vinyl-1-pyrazoline (22) and 3-vinyl-1-pyrazoline-

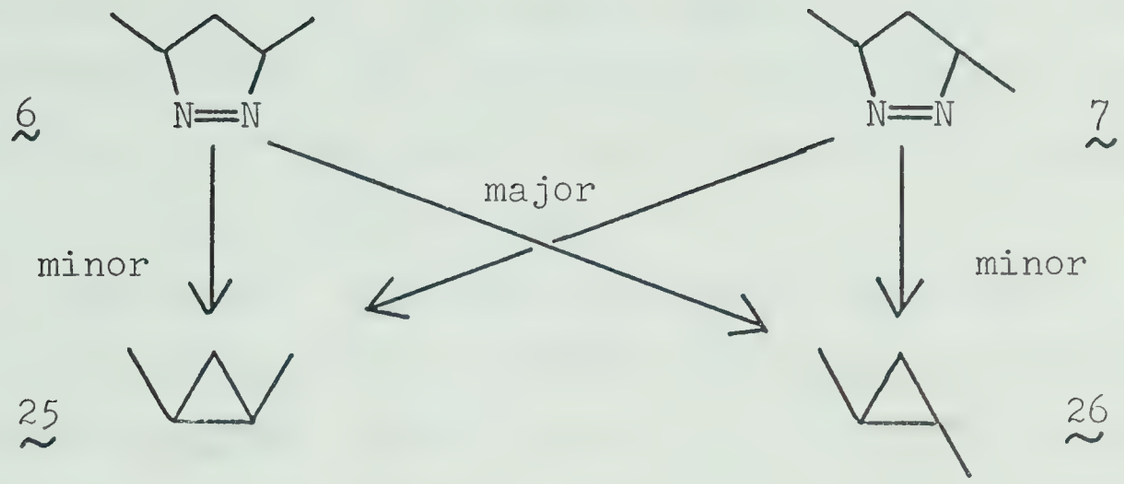
5,5-d_2 (23). It was expected that 22 would undergo thermolysis by a mechanism similar to that of Mishra's methylated pyrazolines. The observed activation energy for the reaction was 32.2 kcal $mole^{-1}$, which represents a decrease of 10.2 kcal $mole^{-1}$ relative to 1-pyrazoline. This decrease was attributed to a contribution from allylic resonance energy, which was suggested to be acting to stabilize the transition state. The value 10.2 kcal $mole^{-1}$, compared with the value 12.6 $\pm$ 0.8 kcal $mole^{-1}$ suggested as the value of the delocalization energy of the allyl radical (9), implies nearly complete delocalization of the electron in the transition state (and thus nearly complete cleavage of the C_3—N bond in the transition state).

The deuterated derivative 23 was synthesized and thermolyzed in order to provide evidence which would allow a choice in this very unsymmetrical pyrazoline between a simultaneous or a sequential bond scission. The thermolysis of 23 showed $\delta\Delta G^{\ddagger}$ = 77 cal, a value which is lower than those observed in the decomposition of other azo compounds (Table II). The interpretation suggested for the results was that while both bonds are undergoing cleavage in the transition state, the C_3—N bond rupture is in advance of the C_5—N bond rupture.

Additional evidence that the slow step involves N_2

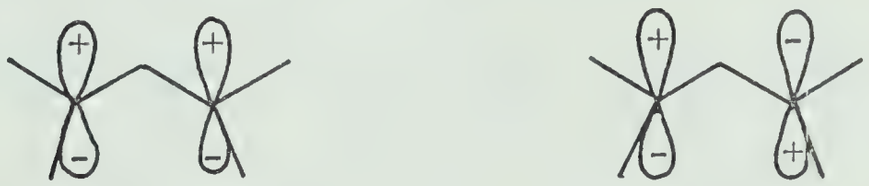
elimination to provide a hydrocarbon intermediate has been provided by Mishra's kinetic and product studies (1a) on the thermolysis of 4-methyl-1-pyrazoline-4-d_1 (24). It was expected that the isotopic substitution would not greatly affect the rate of elimination of nitrogen or of cyclopropane formation from the intermediate, but would be apparent in the rate of formation of olefin, since a hydrogen shift is required. The results confirmed the expectations when it was found that the kinetic isotope effect was small (1.07 ± 0.07) while the mechanistic isotope effect was large (1.80 ± 0.08).

A clue relative to the structure of the intermediate is supplied by the work of Mishra (1), in his study of the isomeric cyclopropanes from the thermolysis of 6 and 7. Each of these pyrazolines gave cis- and trans-dimethylcyclopropanes (25 and 26, respectively) as the major products, and in each case the major cyclopropane isomer was found to be that of opposite stereochemistry (Scheme 1). This indicates that the two radical centers in the intermediate are not free of each other's influence. The formation of products was explained via an intermediate with the hydrogens or substituents on the terminal methylene groups in the plane defined by the three carbon atoms, with the



Scheme 1

lobes perpendicular to the plane. Such an intermediate can exist as a singlet species in one of two symmetry states, the symmetric state 27 or the antisymmetric state 28* (Figure 1). The major products from 6 and 7 can be explained as having arisen by a conrotatory mode



27 28

Figure 1

The π-type molecular orbitals of trimethylene

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* The symmetry operator used here is the mirror-plane that passes through the carbon and two hydrogens of the central methylene group; thus 27 is S, and 28 is A.

of closure of $2\tilde{s}$. Also, species $2\tilde{s}$ is the state which is predicted for the trimethylene intermediate by the application of the orbital symmetry rules for electrocyclic transformations (11).

Theoretical calculations on the trimethylene species carried out by Hoffmann (12) using the extended Hückel molecular orbital method have helped to explain the geometrical and electronic features of the intermediate. Hoffmann investigated the total energy of the species with respect to the three most important degrees of freedom, the central C—C—C angle and the rotations of each of the termini out of the plane. The three limiting geometric configurations which were studied were defined as shown (Figure 2).

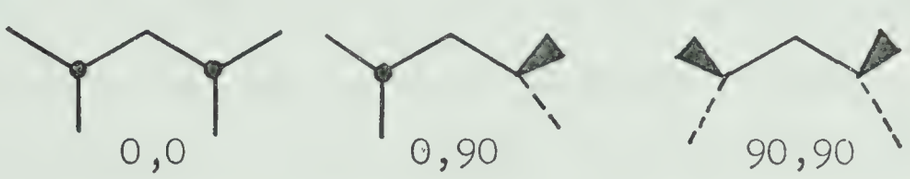


Figure 2

The geometric configurations of trimethylene

On the ground configuration potential surface the most stable point was found to be, as might be expected, a simply opened cyclopropane (i.e., the 90,90 geometry) with a small central angle. A subsidiary minimum was found for the 0,0 geometry with a central angle of

approximately 125°. The easiest passage from the valley of this intermediate to the deeper cyclopropane valley is via a conrotatory motion of the termini.

The excited configuration was found to have a very different potential surface. The result is that the excited configuration is a very loose molecule with no barriers to rotation of the termini, and with the central angle ranging between 100° and 130°.

Considering the electronic levels, $2\tilde{7}$ and $2\tilde{8}$, Hoffmann found that the A level is lower than the S by approximately 0.55 eV. This was attributed to a hyperconjugative interaction between the central methylene and the termini, which destabilizes the S level, leaving the A level unaffected.

Thus the theoretical calculation of the ground state properties may be seen to blend extremely well with the properties deduced for the intermediate from Mishra's work (1). The stable 0,0 geometrical configuration is the configuration which was deduced, and the calculated order of the electronic energy levels is consistent with the observed preference for conrotatory closure to cyclopropane derivatives.

It was also noted by Hoffmann (12) that the order of the electronic energy levels implies that the trimethylene species is an "antiethylene". Thus the con-

certed thermal addition of trimethylene to olefins is allowed (Figure 3).

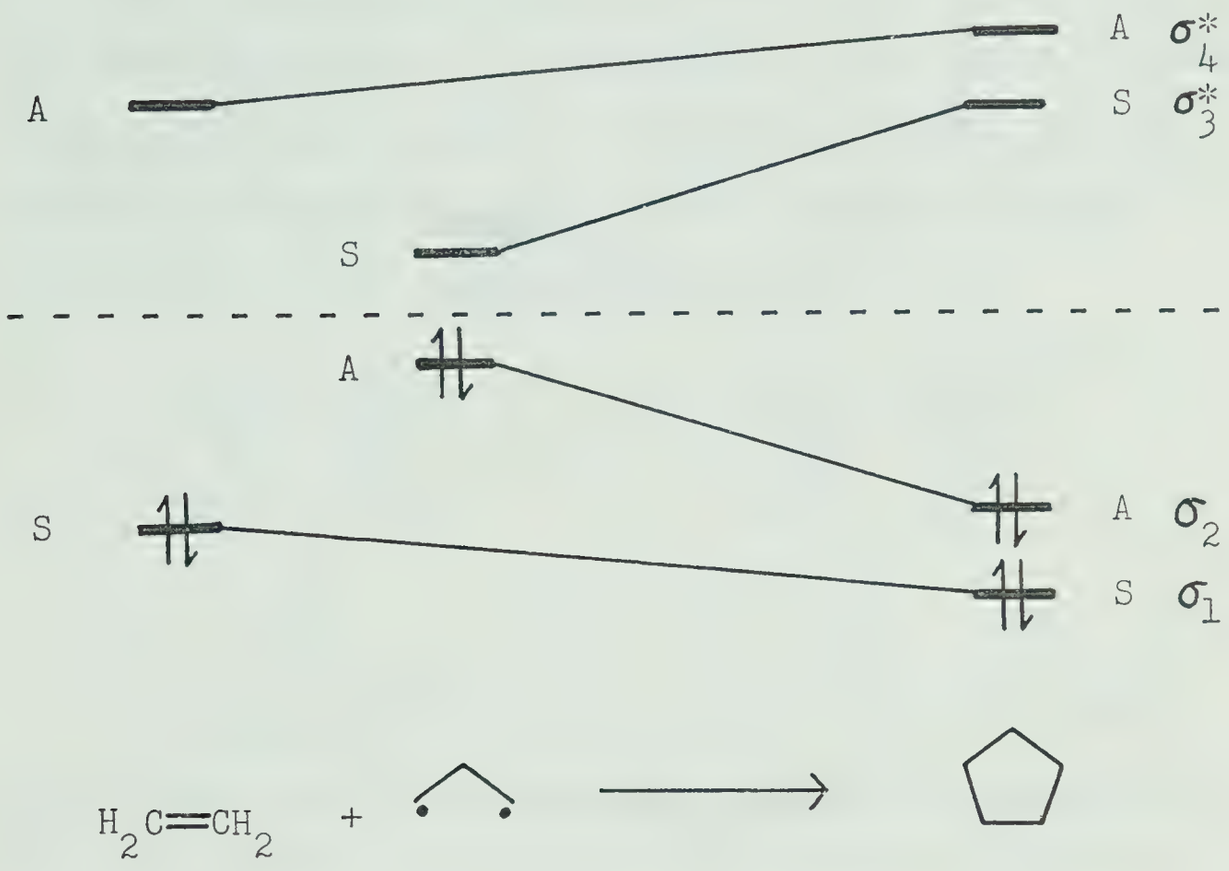


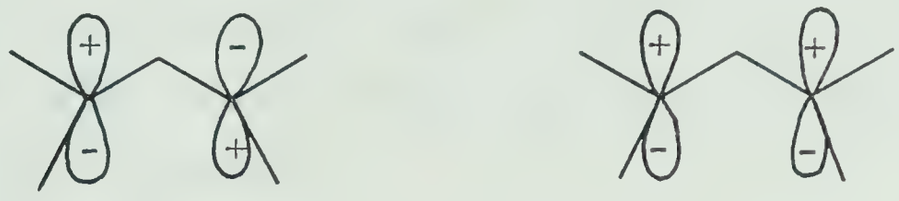
Figure 3

Level correlation diagram

for addition of ethylene to trimethylene

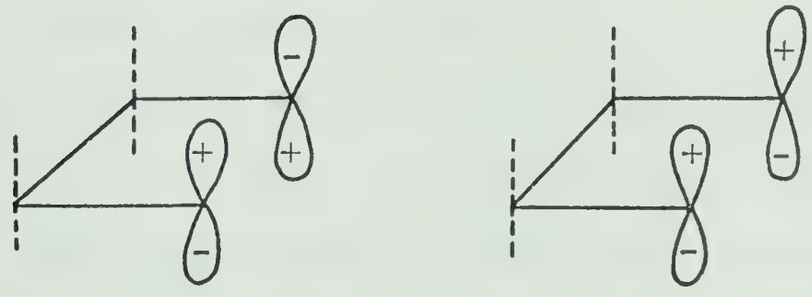
THESIS PROPOSITION

The mechanism proposed by Mishra and Crawford (1) for the thermolysis of 1-pyrazolines involves an intermediate having its highest occupied molecular orbital (HOMO) antisymmetric, 28, and the lowest unoccupied molecular orbital (LUMO) symmetric, 27.



28 27

Consequently the system is analogous to a diene in the symmetry of the HOMO and LUMO, and the trimethylene is expected to act as a "diene-like" species or "antiethylene" (12), undergoing concerted addition to olefins.

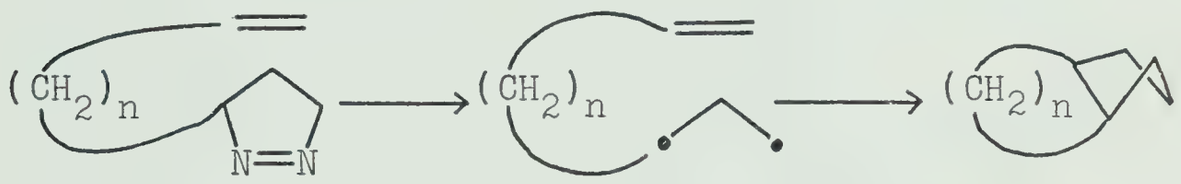


HOMO LUMO

Figure 4

The highest occupied and lowest unoccupied molecular orbitals of a diene

The ease of ring closure, by rotation of the termini, to cyclopropane makes the trimethylene species a very transitory one, with a lifetime in the order of 10^{-10} second. It is therefore highly unlikely that any intermolecular trapping reaction will succeed. An intramolecular trapping experiment has a much greater chance of success, since it is entropy-favored. A pyrazoline with an olefinic bond suitably located within the molecule to act as a trap is required (Scheme II).

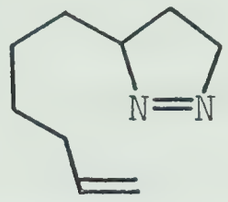


Scheme II

An examination of models indicated that a chain of four methylene groups between the pyrazoline ring and the olefinic bond would be the chain length most likely to bring the olefinic bond into a favorable position for trapping. Because of this and because the cis- and trans-perhydroindanes which would be produced are known to be stable, we have chosen to synthesize this pyrazoline for the experiment.

The synthesis and thermolysis of 3-(5'-hexenyl)-1-pyrazoline (29) as a test of the trimethylene hypo-

thesis is the subject of the remainder of this thesis.



29

EXPERIMENTAL

(A) General Procedures

All boiling points are uncorrected.

Analytical gas chromatography (gc) studies were carried out on an F & M model 500 programmed temperature gc with a Minneapolis-Honeywell strip chart recorder, on a Varian Aerograph model 1200-A programmed temperature gc with a Hewlett-Packard 7127A strip chart recorder, or on a Perkin-Elmer model 900 gc with a Hewlett-Packard 7127A strip chart recorder and a Hewlett-Packard model 3370A integrator.

Preparative gc studies were carried out on an Aerograph model A-700 gc with a Leeds and Northrup Speedomax H strip chart recorder and on an F & M model 700 gc.

Infrared spectra were obtained from a Perkin-Elmer 337 grating infrared spectrophotometer or a Perkin-Elmer 421 grating spectrophotometer. The uv spectra were recorded on a Perkin-Elmer 202 uv-vis spectrophotometer, the nmr spectra on a Varian Associates A-60 spectrometer.

Mass spectroscopy studies were carried out on an AEI MS-12 mass spectrometer, whose ion source was directly coupled by means of a Watson-Biemann helium

separator to a Varian Aerograph model 1200 gc. High resolution mass spectral analyses were obtained using an AEI MS-9 mass spectrometer (70 eV, heated inlet).

Thin layer chromatography (tlc) analyses were obtained using 75 mm-long glass slides coated with a slurry of Merck Silica Gel G in water. Development of the finished plates was carried out by drying on a hot plate followed by spraying first with a 15% (v/v) solution of sulfuric acid in ethanol and then with a 1% solution of vanillin in methanol, followed by heating on a hot plate. In the test the data are reported as follows: solvent mixture, R_f, color of spot.

(B) Synthesis of 3-(5'-Hexenyl)-1-pyrazoline

Tetrahydrofurfuryl chloride (30). Tetrahydrofurfuryl alcohol was allowed to react with thionyl chloride and pyridine according to the method of Brooks and Snyder (13). The product was distilled at 41-44° (11 torr) [lit. (13) bp 41-42° (11 torr)].

4-Penten-1-ol (31). Tetrahydrofurfuryl chloride was allowed to react with a suspension of powdered sodium in ether according to the method of Brooks and Snyder (13). The product was distilled in 87% yield: bp 134-137° [lit. (13) bp 134-137°].

5-Chloro-1-pentene (32). 4-Penten-1-ol was con-

verted to the chloride by the same method as was used for the conversion of tetrahydrofurfuryl alcohol to tetrahydrofurfuryl chloride (13). The product was obtained in about 70% yield*: bp 100-104° [lit. (14) bp 104-105°].

Diethyl α-(4-pentenyl)malonate (33). The procedure was based on that of Vogel (15) for the condensation of diethyl sodiomalonate with n-butyl bromide. The apparatus consisted of a one liter three neck flask equipped with a dropping funnel, a reflux condenser and a magnetic stirring-bar, all oven-dried and flushed with nitrogen. A nitrogen bubbler was used to maintain a nitrogen atmosphere in the apparatus during the reaction. Sodium (12.2 gm, 0.52 mole) was dissolved with stirring in 500 ml dry ethanol, freshly distilled from CaH_2. The sodium ethoxide solution was cooled to room temperature and then was stirred rapidly while freshly distilled diethyl malonate (85.0 gm, 0.53 mole) was added over a 15 min period from the dropping funnel. 5-Chloro-1-pentene (52.5 gm, 0.50 mole) was then poured into the dropping funnel. A small amount was run into the flask, and the solution was heated gently

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* The yield varied widely for reasons which were not readily apparent.

in an oil bath until the appearance of a precipitate of sodium chloride showed that the reaction had started. Then the remainder of the chloride was added, dropwise, over a 30 min period, while stirring was continued. After the addition was complete the reaction mixture was brought to reflux. Stirring under reflux was continued for a further 24 hr, and then most of the ethanol was slowly distilled out. The reaction mixture was cooled and filtered to remove the sodium chloride. Water (150 ml) was added to the filtrate, and the crude product was separated from the aqueous phase in a separatory funnel. The product was washed well with water, dried (Na_2SO_4), and concentrated on a rotary evaporator. Distillation gave 86 gm (75%): bp 90-95° (1 torr) [lit. (16) bp 130-136° (14 torr)]; tlc, 10% methanol in benzene, 0.70, blue-black.

6-Heptenoic acid (34). This acid was prepared by hydrolysis and decarboxylation of diethyl α-(4-pentenyl) malonate by a procedure based on that of Vogel (17). The hydrolysis apparatus consisted of a two liter three neck flask equipped with a mechanical stirrer, a dropping funnel and a reflux condenser. A solution of sodium hydroxide (175 gm, 4.40 moles) in 300 ml ethanol containing 30 ml water was placed in the flask. The ester (260 gm, 1.34 moles) was added slowly from the

funnel. Very strong stirring was necessary because of foaming. The mixture was heated on an oil bath to maintain gentle reflux during the addition of the ester. When the addition was completed the ethanol was distilled slowly from the flask until 170 ml had been collected (boiling range 73-79°). The solution of the diacid salt was then cooled to room temperature and ice was added. An ice-cold solution of sulfuric acid (226 gm, 2.21 moles) in 250 ml water was then added carefully, with stirring. Water was added to dissolve the precipitate, and the product was extracted thoroughly with ether. The combined ether extract was washed with water, dried (Na_2SO_4) and concentrated on a rotary evaporator until the product solidified.

The diacid (wt 219 gm) was decarboxylated, without any further purification, by heating on an oil bath to 150° in a one liter flask equipped with a magnetic stirrer and a Claisen distilling head with an air condenser. Approximately 20 ml of low-boiling material distilled quickly (temperature 35-85°; ether, ethanol, water). The decarboxylation was continued for four hr at 155-160°, and then a clean distilling head, condenser, and receiver were attached to the flask while the oil bath cooled. The product was distilled directly, giving 132 gm (90% for two steps) of 6-heptenoic acid:

bp 125-128° (15 torr) [lit. (16) bp 125° (15 torr), (18) bp 118-120° (10 torr), (19) bp 70-72° (0.5 torr)]; tlc, 10% methanol in benzene, 0.55, orange-brown.

6-Heptenoyl chloride (35). Thionyl chloride and 6-heptenoic acid were allowed to react according the the procedure of Vogel (20). Freshly distilled thionyl chloride (139 gm, 1.17 moles) was poured into a one liter three neck flask equipped with a 250 ml dropping funnel, a reflux condenser, a magnetic stirring-bar and a drying tube. A bubbler was connected to the drying tube to aid in determining when the reaction was finished. While the solution was stirred, the acid (130 gm, 1.02 moles) was added, dropwise, over a period of one hr. After the addition was complete the temperature of the solution was raised slowly while stirring was continued. Over a period of 30 min the temperature was raised to 85°. Evolution of gas ceased at that point, and the solution was cooled and distilled. The excess thionyl chloride was removed by gradually lowering the pressure before vacuum distillation of the acyl chloride. The yield was 141 gm (94%): bp 73-77° (18 torr) [lit. (18) bp 63-64° (8 torr), (21) bp 69° (17 torr), (19) bp 30-35° (1 torr)]; nmr, see Table III; tlc, 10% methanol in benzene, 0.80, brown; 14% ethyl acetate in pentane 0.65, orange.

Ethyl 2-Acetyl-3-oxo-8-nonenoate (36). The condensation of 6-heptenoyl chloride with the magnesio derivative of ethyl acetoacetate was carried out according to the procedure of Viscontini (22). A three liter three neck flask was equipped with a mechanical stirrer, a dropping funnel, a reflux condenser, a drying tube and a magnetic stirring-bar, all of which had been oven-dried. The apparatus was flushed with nitrogen, and 27.8 gm (1.15 moles) magnesium turnings were place in the flask after having been washed with dry ether. Absolute ethanol (133 gm, 2.88 moles) was added in portions (0.5 ml CCl_4 was used to start the reaction) from the dropping funnel. Ether was then added at intervals to wash the magnesium surface in order to induce the reaction. Stirring was only intermittent, serving to agitate the mixture slightly. After ten hr, 500 ml ether had been added, and the reaction was essentially complete. Another portion of 500 ml ether was added, and the mixture was gently stirred overnight.

The mixture was then cooled to 0° in an ice bath, and an ice-cold solution of ethyl acetoacetate (128 gm, 0.98 mole) in 200 ml ether was added from the separatory funnel over 45 min. After an additional hr of stirring, the reaction mixture was cooled to -10° in an ice-salt bath, and a cold solution of 6-heptenoyl

chloride (140 gm, 0.96 mole) in 150 ml ether was added dropwise while the reaction was stirred vigorously with a mechanical stirrer. The temperature was held between -10° and -5° during the addition and then was allowed to warm slowly to room temperature with continued stirring.

A 10% excess portion of ice-cold dilute sulfuric acid was added carefully to the mixture, and the ether phase was separated and washed. The aqueous phase was thoroughly extracted with ether (6 x 100 ml), and the combined ether solution was washed with saturated aqueous $NaHCO_3$ and then with saturated aqueous NaCl solution and with water, was dried (Na_2SO_4), concentrated and distilled. The amount was 180 gm (78%): bp 94-97° (0.1 torr); nmr, see Table III; tlc, 10% methanol in benzene, 0.65, blue-green; 14% ethyl acetate in pentane, 0.80, olive green; 15% acetone in Skelly B, 0.55. No analysis was obtained, as the compound was difficult to purify.

Methyl 3-Oxo-8-nonenoate (37). Ethyl 2-acetyl-3-oxo-8-nonenoate was saponified according to the procedure of Hunsdiecker (23). A two liter three neck flask was equipped with a dropping funnel, a reflux condenser, a magnetic stirring-bar and a drying tube, all of which had been oven-dried. Sodium (20.4 gm,

0.89 mole), in pieces, was dissolved in 700 ml dry methanol in the flask. The cooled solution was stirred rapidly while 178 gm (0.74 mole) of ethyl 2-acetyl-3-oxo-8-nonenoate in 150 ml dry methanol was added from the dropping funnel. Stirring was continued for four hr at room temperature, and then a 10% excess portion of ice-cold dilute sulfuric acid was added. Water was added to dissolve the precipitate, and the product β-keto ester was extracted with ether (6 x 125 ml). The combined ether solution was washed thoroughly, neutralized with saturated aqueous $NaHCO_3$, then washed with saturated aqueous NaCl solution, water, dried ($MgSO_4$), concentrated, and distilled, yielding 113 gm (83%) of methyl 3-oxo-8-nonenoate: bp 70° (0.07 torr) [lit. (21) bp 95-102° (0.5 torr)]; nmr, see Table III; tlc, 10% methanol in benzene, 0.80, yellow-brown; 14% ethyl acetate in pentane, 0.55, yellow-green; 15% acetone in Skelly B, 0.80, purple.

7,9-Dihydroxy-1-nonene (38). Methyl 3-oxo-8-nonenoate was treated with lithium aluminum hydride by a method analogous to that of Vogel (24). A two liter three neck flask equipped with a mechanical stirrer, reflux condenser and dropping funnel, all oven-dried, was fitted with a nitrogen bubbler and flushed with nitrogen. Powdered lithium aluminum hydride (10.6 gm,

0.27 mole) was dissolved in 700 ml dry tetrahydrofuran in the flask, and a solution of methyl 3-oxo-8-nonenoate (50.0 gm, 0.27 mole) in 150 ml dry tetrahydrofuran was added at a rate sufficient to maintain gentle reflux while the solution was stirred. The addition required 90 min. An oil bath was used to maintain reflux temperature for an additional two hr. The workup was carried out as described by Mićović and Mihailović (25). The reaction mixture was cooled and stirred in an ice bath and decomposed by dropwise addition of water, 15% NaOH and more water. After 20 min further stirring, the mixture was vacuum filtered using a sintered-glass filter. The precipitate was washed with four 50 ml portions of ether, which were added to the filtrate. The organic solution was then concentrated on the rotary evaporator to remove the tetrahydrofuran. Ether (500 ml) was added to the crude product, and the solution was washed to neutrality, dried ($MgSO_4$), concentrated and distilled. The yield of product diol was 23.4 gm (90% pure by gc analysis, 50% yield): bp 80° (0.06 torr); nmr, see Table III; mass spectrum, see Figure 6; ir, 3200-3500 cm^{-1} (hydroxyl), 3090 cm^{-1}, (olefinic C—H), 1655 cm^{-1}, (olefinic C=C), 920 and 995 cm^{-1} (vinyl); tlc, 10% methanol in benzene, 0.35, purple-black; 14% ethyl acetate in pentane, 0.10; 15%

acetone in Skelly B, 0.20, black.

7,9-Dichloro-1-nonene (39). The method of Hooz (26) was employed for the conversion of 7,9-dihydroxy-1-nonene to 7,9-dichloro-1-nonene. A 200 ml three neck flask was equipped with a 50 ml dropping funnel, a reflux condenser, and a magnetic stirring-bar, all oven-dried. A nitrogen bubbler was attached, and the apparatus was flushed with nitrogen. Freshly distilled tri-n-butyl phosphine (37.4 gm, 185 mmoles) was poured into the dropping funnel, and a solution of diol (12.8 gm, 81 mmoles) in carbon tetrachloride (40 ml) was poured into the flask. The flask was immersed in a water bath to help moderate the temperature (the reaction is extremely exothermic), and the solution was stirred rapidly while the phosphine was added over a period of 30 min. Stirring was continued for 90 min at room temperature, and the chloroform and carbon tetrachloride were distilled through a 20 cm Vigreux column.

Distillation of the product at this point did not give clean dichloride. A careful fractionation always left the product contaminated with a large amount of material with a much longer retention time on the gc column (10' x 1/8" 10% SF-96 on Chromosorb W). This was probably tri-n-butyl-phosphine, and/or

tri-n-butyl phosphine oxide.

Column chromatography was used for the isolation of pure 7,9-dichloro-1-nonene. Addition of pentane to the concentrate of the reaction mixture (after removal of chloroform and carbon tetrachloride) caused separation of a large amount of thick syrup. This was thoroughly extracted by stirring with pentane, and the decanted pentane solutions were combined and concentrated. The crude product was chromatographed on Fisher alumina, and the pentane eluate was concentrated to give pure 7,9-dichloro-1-nonene in about 60% yield: bp 65-75° (0.10 torr); nmr, see Table III; mass spectrum, see Figure 6; ir, 3080 cm^{-1} (olefinic C—H), 1645 cm^{-1} (olefinic C=C), 995 and 915 cm^{-1} (vinyl); tlc, 10% methanol in benzene, 0.95; 14% ethyl acetate in pentane, 0.90.

3-(5'-Hexenyl)pyrazolidine (40). The pyrazolidine was produced by the reaction of hydrazine with 7,9-dichloro-1-nonene in ethanol solution, analogous to the method of Mishra (1). A 100 ml three neck flask with a reflux condenser, a dropping funnel, a magnetic stirring-bar and a nitrogen bubbler was flushed with nitrogen. A solution of 95% hydrazine (4.25 gm, 125 mmoles) in absolute ethanol (30 ml) with approximately 2 mg of EDTA was stirred vigorously in the flask at 0-5°,

while a solution of 7,9-dichloro-1-nonene (8.0 gm, 41 mmoles) in absolute ethanol (10 ml) was added from the funnel. The addition required 15 min. Stirring was continued while the reaction was allowed to warm to room temperature and then was heated to reflux. The disappearance of dichloride was monitored by gc (10' x 1/8" 10% SF-96 on Chromosorb W, 120°), while stirring at reflux was continued for 120 hr.

After completion of the reaction, the solution was cooled to 0°, and the precipitate (hydrazine hydrochloride) was filtered and washed with several portions of ethanol, which were added to the solution. An excess of solid KOH pellets was added to the solution, and it was stirred for an hr at room temperature and let stand overnight at -15° before filtering. The filtrate, with the ethanolic washings of the precipitate, was concentrated at atmospheric pressure under a 20 cm Vigreux column and then cooled and filtered to remove another portion of solids.

The remaining ethanol was removed by distillation at reduced pressure, beginning at -20° and working the pressure downward to 0.2 torr and then allowing the temperature to rise to room temperature. The product was separated from another batch of solids by addition of ether and filtration. The ether was removed by

distillation at reduced pressure, and the product was distilled at 0.05 torr, bath temperature 70°; wt 1.97 gm (31%); nmr, see Table III. No analysis was obtained, since pyrazolidines are known to give unreliable analyses (1).

The residue consisted of a series of compounds much more slowly eluted on the gc (10' x 1/8" 10% SF-96 on Chromosorb W).

3-(5'-Hexenyl)-1-pyrazoline (29). The oxidation of pyrazolidine with HgO in ether, according to the method of Mishra (1), was used for the preparation of the 1-pyrazoline. A suspension of HgO (3.0 gm, 13.8 mmoles) and Na_2SO_4 (4.0 gm) in 6 ml ether was stirred in a 25 ml flask immersed in an ice bath. A solution of 3-(5'-hexenyl)pyrazolidine (1.63 gm, 10.6 mmoles) in 2 ml ether was added to the flask, and the flask was wrapped in aluminum foil to keep light out. The temperature was allowed to rise to room temperature, and stirring was continued while the progress of the reaction was followed by gc (5' x 1/8" 3% SE-30 on Varaport, 100°). After 48 hr a further portion of HgO (1.0 gm, 4.6 mmoles) was added, along with 2 ml ether. This accelerated the reaction, so a further portion of HgO (0.5 gm, 2.3 mmoles) was added after 4 more hr, and the reaction was stirred for a further 24

hr, until the hydrazo compound was completely oxidized. The solution was decanted from the flask, and ether washings of the solids were added to the solution.

The ether was distilled through a 15 cm Vigreux column, the last portion at reduced pressure and temperature. The product was distilled by trap-to-trap transfer (bath temperature 60-90°, pressure 0.10 torr) leaving a brown residue. The product (400 mg) was about 85% pure according to gc analysis (5' x 1/8" 3% SE-30 on Varaport, 80°), with one major, more rapidly eluted impurity. The pyrazoline was purified by preparative gc (5' x 3/8" UCON 50 LB 550X on Fluoropak, 100°); nmr, see Table III; mass spectrum, see Figure 6; exact mass 152.1311, calculated for $C_9H_{16}N_2$, 152.13134; ir, 3075 cm^{-1} (olefinic C—H), 1635 cm^{-1} (olefinic C=C), 1545 cm^{-1} (N=N), 990 and 905 cm^{-1} (vinyl), no absorption above 3100 cm^{-1}, that is, no N—H.

(C) Syntheses of Authentic Samples

6-Cyclopropyl-1-hexene (41). The cuprous chloride-catalyzed reaction of diazomethane with 1,7-octadiene was used to prepare this compound. The procedure was that of Pincock (27).

The diazomethane generator was a 250 ml three

neck flask equipped with a magnetic stirring-bar, an inlet tube carrying a stream of nitrogen and an outlet tube leading through a potassium hydroxide-soda lime drying tube to an inlet tube running to the bottom of the reactor flask. Into the generator was poured 45 ml of a 50% aqueous KOH solution and 100 ml of ether. The mixture was stirred in an ice bath. The reactor flask was a 50 ml three neck flask with a condenser, a magnetic stirring-bar and the above-mentioned inlet tube. A solution of 3 gm 1,7-octadiene in 20 ml ether and 400 mg cuprous chloride was added and was stirred in an ice bath.

The nitrogen stream was adjusted to a flow of 60 ml/min, and 2 gm portions of N-nitroso-N-methyl urea were spooned into the generator at intervals so that a steady stream of diazomethane at low concentration was carried into the reactor flask. The progress of the reaction was monitored by gc (10' x 1/8" 10% SF-96 on Chromosorb W) and the reaction was stopped at 25% completion.

The ethereal solution was filtered and concentrated on a spinning band column. Preparative gc (6' x 1/4" SF-96 column) was used for isolation of a sample of pure 6-cyclopropyl-1-hexene, which was identified by nmr and mass spectral analyses; nmr, see

Table III; mass spectrum, see Figure 7.

trans- (42) and cis-Perhydroindane (43). Indane was reduced catalytically at high temperature and pressure with Raney nickel. The product was equilibrated in a sealed tube with palladium on carbon to give a mixture of trans- and cis-perhydroindanes, according to the procedure of Allinger (28). Identification of the isomers was based on the published relative retention times (28) and on mass spectral analysis (29).

Indane (9.8 gm) was dissolved in ethanol (170 ml) and placed in a 480 ml bomb with 2 tsp of freshly prepared W-2 Raney nickel. The bomb was pressurized with 110 atmospheres H_2 and was rocked for 15 hr at 160°. After the bomb was cooled and opened, the ethanolic solution was filtered and concentrated by distillation through a spinning band apparatus. The product was quickly distilled. Analysis on four gc columns (10' x 1/8" 15% tris-β-Cyanoethoxypropane on 60-80 mesh Chromosorb P, 10' x 1/8" β,β'-Oxidipropionitrile on Chromosorb W, 10' x 1/8" 10% SF-96 on 60-80 mesh Chromosorb W, and 12' x 1/8" 10% Squalane on Chromosorb P) showed almost exclusive formation of one product. On each column there was a very small peak which was eluted before the main product. The published retention times (28) on a tris-β-Cyanoethoxy-

propane column are 19 min for 42 and 26 min for 43; this makes it likely that the major product was 43. An nmr spectrum of a portion of the major product isolated by preparative gc (β,β'-Oxidipropionitrile) showed no aromatic or olefinic absorption.

A 0.5 ml portion of the material was heated in a sealed tube (7 mm i.d. x 200 mm) with 200 mg 5% palladium on carbon at 285-288° for 120 hr, cooled quickly and opened. Ether was added, the solid was removed by filtration, and the ethereal solution was analyzed by gc (β,β'-Oxidipropionitrile and tris-β-Cyanoethoxypropane). This showed 43 to be the major compound present, with a greatly increased proportion of the more rapidly eluted compound (42) as well as a third major peak, in smaller amount, which, based on the retention time, appeared to be indane.

The identities of 42 and 43 and of indane were confirmed by their mass spectra (29); see Figure 7.

(D) Thermal Decomposition of 3-(5'-hexenyl)-1-pyrazoline

The pyrolysis studies were carried out in a large, well-insulated, covered oil bath. The temperature was controlled by a Melabs Proportional Temperature Controller, model CTC-1A, used in conjunction with an auxiliary immersion heater. The temperature was measured with a

Hewlett-Packard 2801A (NBS) quartz thermometer and checked against a four-junction iron-constantan thermocouple using a reference ice bath, which was read with a Rubicon Instruments Model 2713 potentiometer. The bath temperature was maintained within ± 0.02°.

Pyrolysis tubes were constructed of Pyrex glass, as shown in Figure 5. The volume was approximately 15 ml.

A mixture of authentic samples of the expected products, 41, 42 and 43, was prepared and analyzed. Relative retention times were determined on two different analytical columns (150' x 0.01" SE-30 and 150' x 0.01" β,β'-Oxidipropionitrile). Results are shown in Tables IV and V, respectively. An analysis of the proportion of each compound in the mixture was carried out on the SE-30 column as shown in Table VI. This analysis was not carried out on the β,β'-Oxidipropionitrile column because 41 and 42 were not completely resolved.

A sample of the pyrazoline (29) (10 μl, approximately 50 μmoles) was injected by syringe into the pyrolysis tube; the tube was connected to the vacuum line by a length of polyethylene tubing and immersed in liquid nitrogen. The tube was evacuated and then thawed after the vacuum stopcock was closed. The sample was

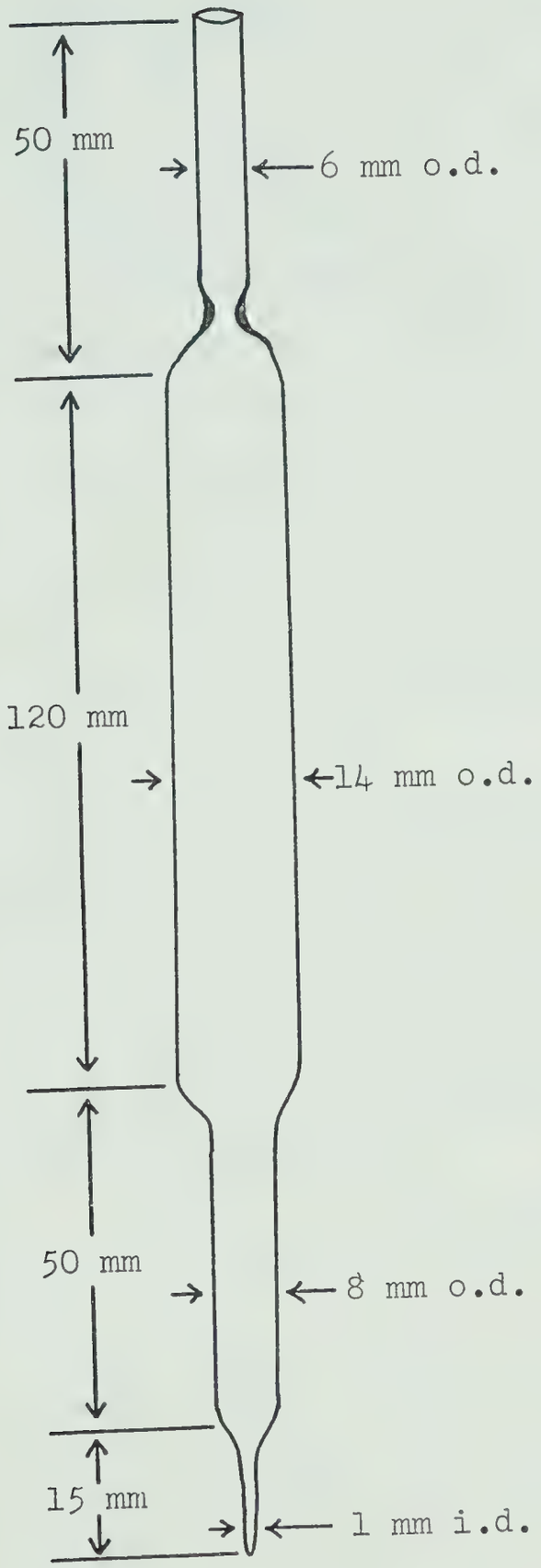


Figure 5

Diagram of a Pyrex pyrolysis tube

worked into the capillary section by vapor transfer, frozen, and degassed. After being sealed, the tube was fused to a length of glass rod, by which it was immersed into the thermostated oil bath.

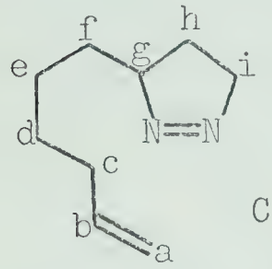
The sample was pyrolyzed 30.0 min at a bath temperature of 200.52° ± 0.02°, and was then cooled to room temperature and frozen in liquid nitrogen. A hot-air blower was used briefly to evaporate the liquid and to transfer it to the capillary section. The tube was then broken near the top of the 8 mm section and was closed with a serum cap and stored at 0° while analyses were carried out.

The product mixture was analyzed for the presence of 41, 42 and 43 in the same manner that the authentic sample mixture was analyzed. The results, showing relative retention time and proportion of each product on SE-30 and on β,β'-Oxidipropionitrile are shown on Tables VII and VIII, respectively.

Table III

Nmr data

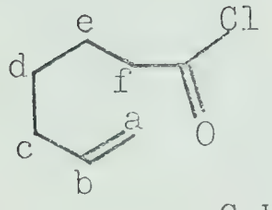
All spectra were taken in $CDCl_3$ unless otherwise specified. All shifts are reported as τ values.



$C_9H_{16}N_2$

29

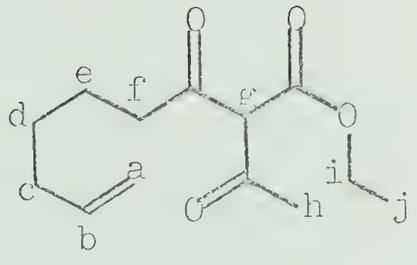
Neat; τ4.55 (m, 0.86 H, b), 5.40 (m, 1.94 H, a), 5.85-6.7 (complex, 2.76 H, g and i), 8.1-9.6 (complex, 10.4 H, c, d, e, f and h).



$C_7H_{11}ClO$

35

τ4.2 (m, 1.00 H, b), 5.0 (m, 1.98 H, a), 7.1 (t, 1.82 H, f), 7.6-8.9 (complex, 6.08 H, c, d and e, includes br quartet at 7.95 for allylic protons c).



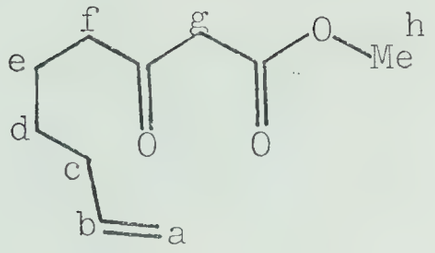
$C_{13}H_{20}O_4$

36

τ4.2 (m, 0.85 H, b), 5.0 (m, 2.07 H, a), 5.7 (quartet, 1.96 H, $\underline{J}$ = 7 Hz, i), 7.35 (t, 2.08 H, $\underline{J}$ = 7 Hz, f), 7.6-8.85 (complex, 13.1 H, c, d, e, g, h and j, includes s, 7.7, h; t, 8.7, $\underline{J}$ = 7 Hz, j; br quartet, 7.95, c).

(cont'd.)

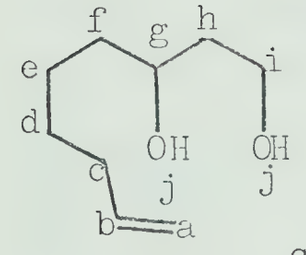
Table III (cont'd.)



$C_{10}H_{16}O_3$

37

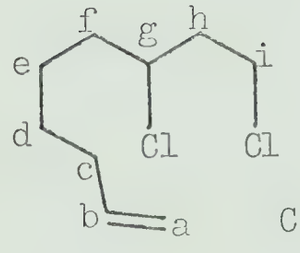
τ4.2 (m, 0.85 H, b), 5.0 (m, 2.20 H, a), 6.25 (s, 2.90 H, h), 6.55 (s, 1.80 H, g), 7.3-8.9 (complex, 8.02 H, c, d, e and f; includes br t, 7.45, f, br quartet, 7.95, c).



$C_9H_{18}O_2$

38

τ4.2 (m, 1.08 H, b), 4.95 (m, 2.02 H, a), 6.2 (t, 3.06 H, g, and i), 6.4 (s, 2.02 H, j), 7.95 (br quartet, 2.02 H, c), 8.2-8.8 (complex, 7.81 H, d, e, f and h).



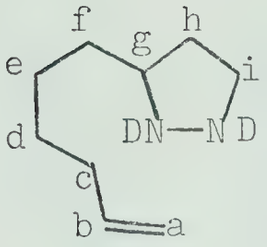
$C_9H_{16}Cl_2$

39

τ4.2 (m, 0.99 H, b), 5.0 (m, 1.98 H, a), 5.9 (m, 1.02 H, g), 6.3 (t, 1.87 H, J = 6, i), 7.7-8.1 (m, 4.1 H, c and h), 8.1-8.8 (m, 6.06 H, d, e and f).

(cont'd.)

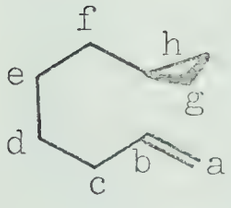
Table III (cont'd.)



$C_9H_{16}D_2N_2$

40-d_2*

Solvent, D_2O-DCl; τ4.0 (m, 1.0 H, b) 4.9 (m, 2.0 H, a), 6.2 (complex, 2.4 H, i), 6.7 (complex, 1.5 H, g), 7.35 (br t, 1.7 H, c), 7.9 (br m, 2.0 H, h) 8.4 (complex, 6.0 H, d, e and f).



C_9H_{16}

41

τ4.2 (m, 1.08 H, b), 5.05 (m, 2.00 H, a), 7.95 (br quartet, 2.08 H, c), 8.65 (complex, 5.93 H, d, e and f), 9.5 and 10.0 (multiplets, 3.05 and 1.88 H, respectively, g and h).

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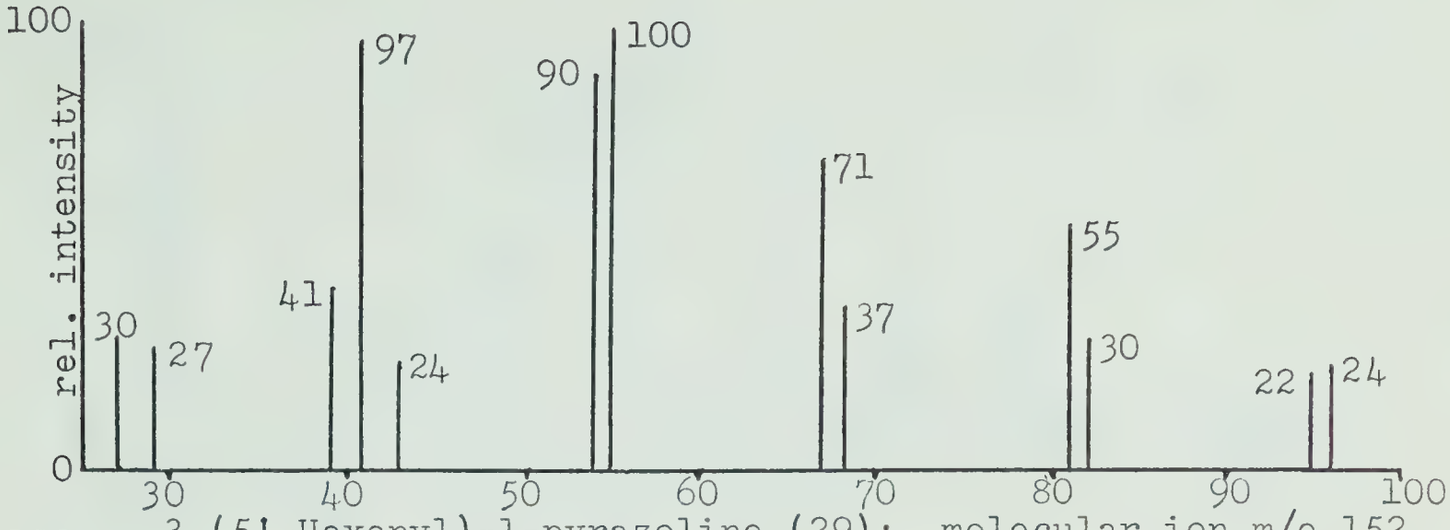
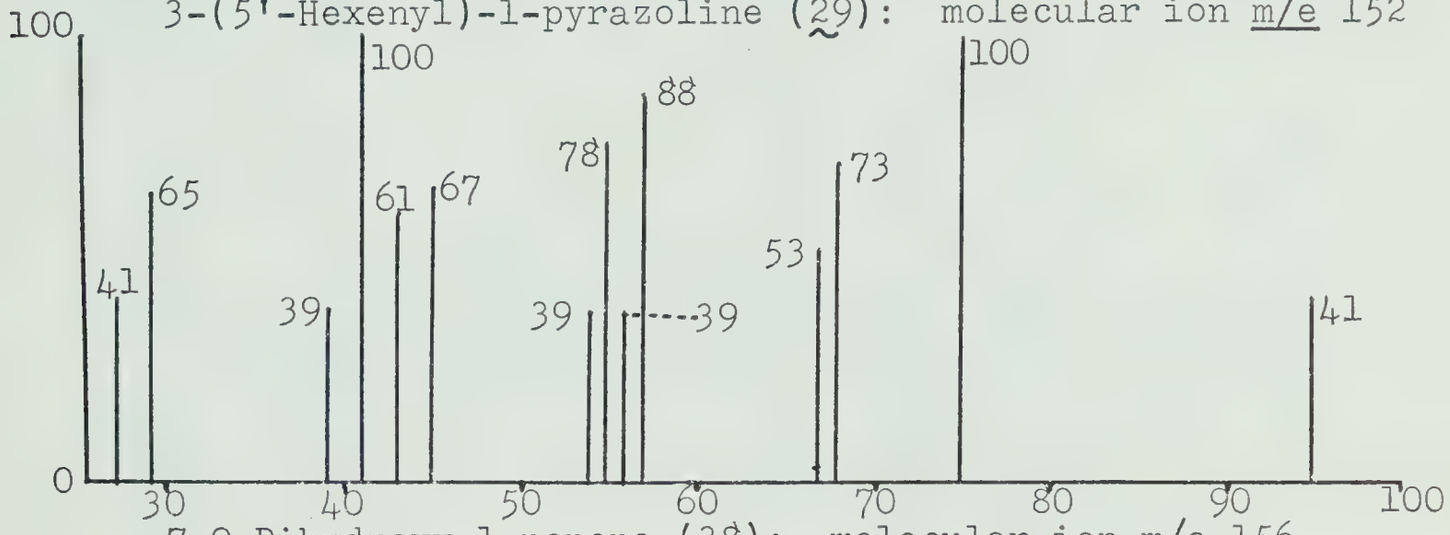
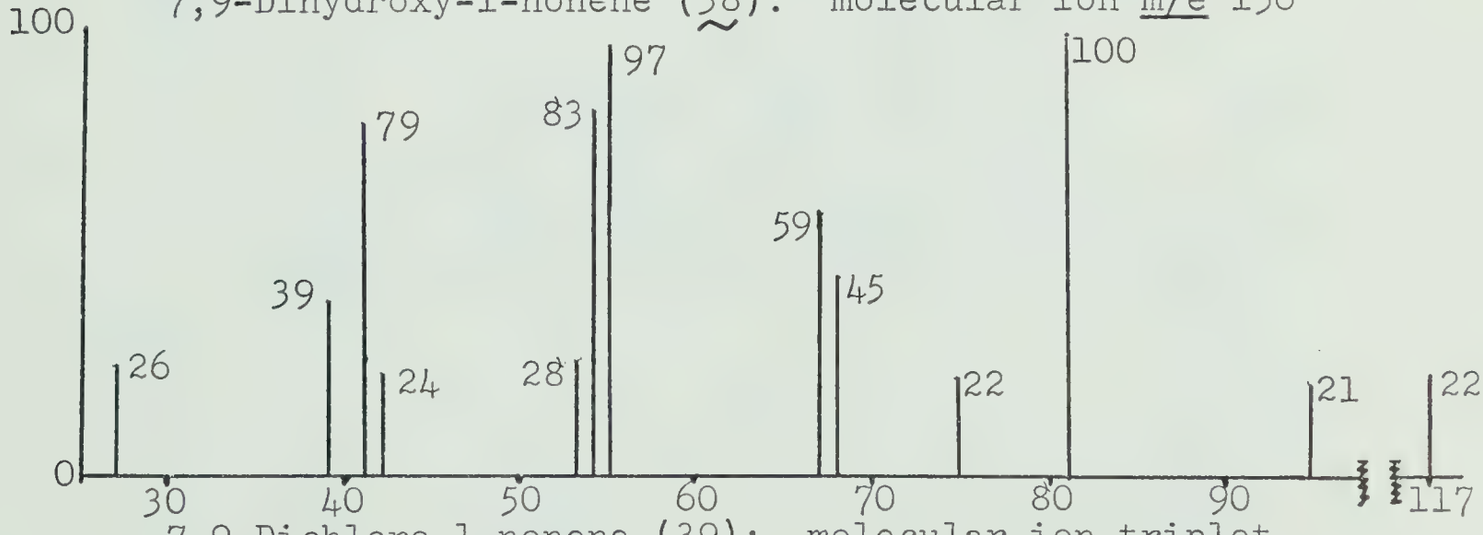
* 40 was dissolved in D_2O-DCl; thus the N—H protons were largely exchanged.



3-(5'-Hexenyl)-1-pyrazoline (29): molecular ion m/e 152



7,9-Dihydroxy-1-nonene (38): molecular ion m/e 156



7,9-Dichloro-1-nonene (39): molecular ion triplet m/e 194, 196, 198

Figure 6

Mass spectra of some compounds

in the synthetic scheme

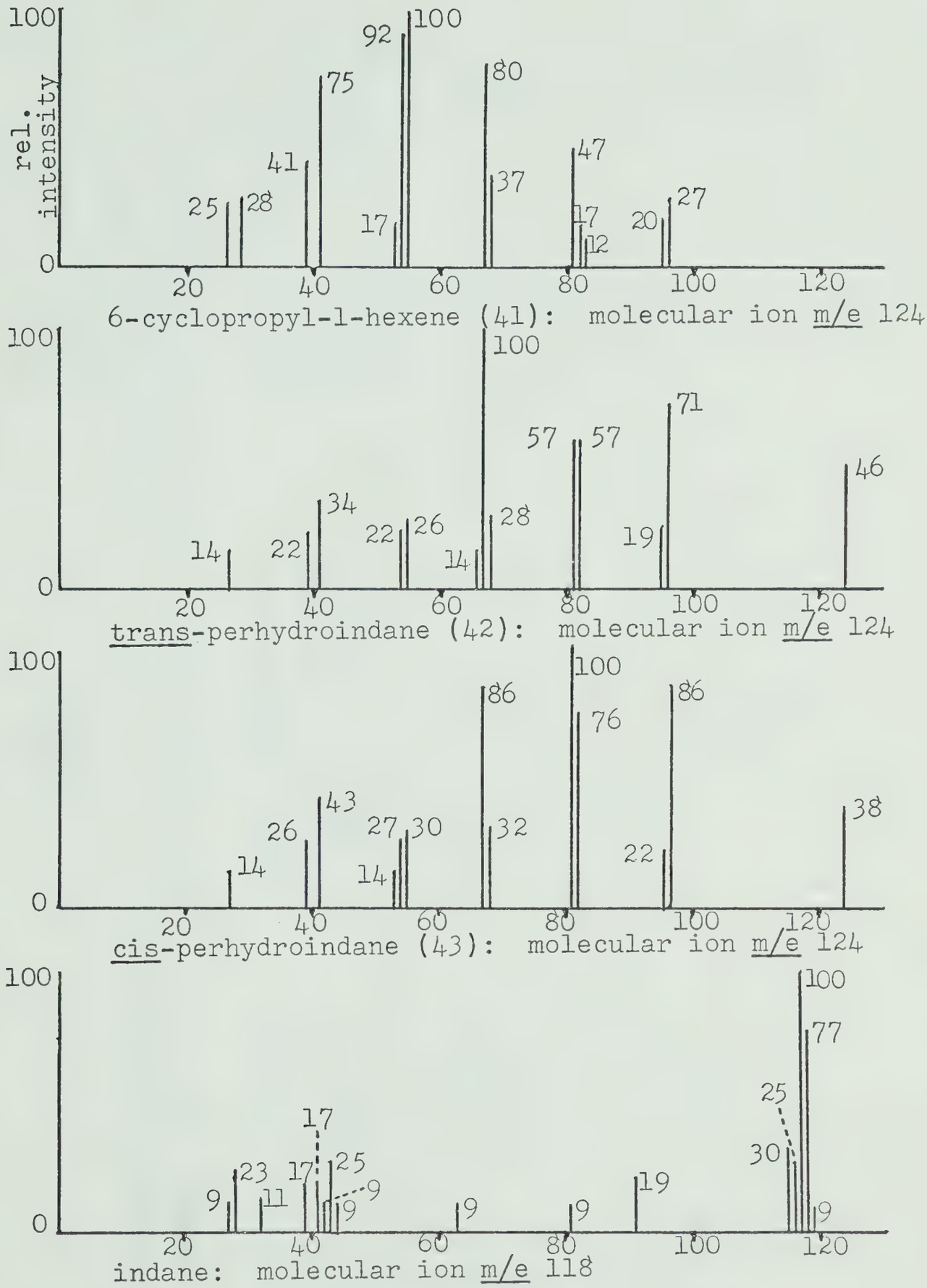


Figure 7

Mass spectra of the compounds

in the authentic sample mixture

Table IV

Relative retention time data for the authentic sample mixture on SE-30

Column: 150' x 0.01" SE-30; helium pressure 20#/in^2; temperature 60°

6-Cyclopropyl-1-hexene		*trans*-Perhydroindane		*cis*-Perhydroindane	
Retention Time (Min)	Relative Retention Time	Retention Time (Min)	Relative Retention Time	Retention Time (Min)	Relative Retention Time
10.31	1.000	12.87	1.248	15.56	1.509
10.45	1.000	13.05	1.249	15.80	1.512
10.46	1.000	13.07	1.250	15.81	1.511
10.85	1.000	13.59	1.252	16.50	1.520
10.85	1.000	13.60	1.253	16.54	1.524
10.92	1.000	13.66	1.251	16.56	1.516
			mean = 1.2505		1.5153
			σ = 0.0019		0.0058

Table V

Relative retention time data for the authentic sample mixture on β,β'-Oxidipropionitrile

Column: 150' x 0.01 " β,β'-Oxidipropionitrile; helium pressure 20#/in^2; temperature 40°

6-cyclopropyl-1-hexene		trans-perhydroindane		cis-perhydroindane	
Retention Time (Min)	Relative Retention Time	Retention Time (Min)	Relative Retention Time	Retention Time (Min)	Relative Retention Time
8.26	1.000	8.68	1.050	11.15	1.350
9.10	1.000	9.53	1.047	12.29	1.349

Table VI

Analysis of the authentic sample mixture for proportions of components

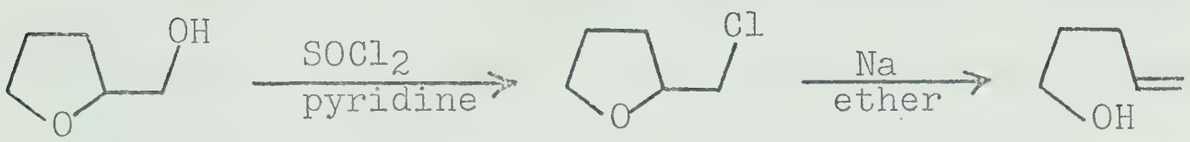
Column: 150' x 0.01" SE-30; helium pressure 20#/in^2; temperature 60°

6-cyclopropyl-1-hexene		trans-perhydroindane		cis-perhydroindane	
Integration	% of Total	Integration	% of Total	Integration	% of Total
5437	16.24	11200	33.46	16830	50.28
5184	16.29	10590	33.29	16030	50.40
4866	16.20	9995	33.29	15160	50.49
5058	16.15	10400	33.21	15850	50.62
6057	16.19	12490	33.38	18860	50.41
4936	16.20	10130	33.26	15390	50.53
mean =	16.212		33.315		50.455
σ =	0.048		0.090		0.118

RESULTS

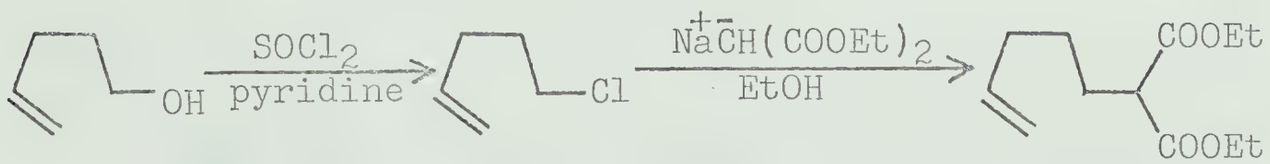
(A) Synthetic Study

The synthesis of pyrazoline 29 started from tetrahydrofurfuryl alcohol, which was converted to the chloride 30 by reaction with thionyl chloride in pyridine. Treatment of 30 with sodium in ether converted it to the alcohol 31.



30 31

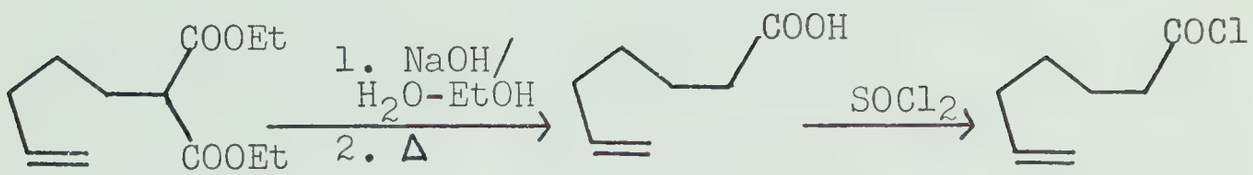
Treatment of 31 with thionyl chloride in pyridine converted it to the chloropentene 32, which was condensed with diethyl sodiomalonate in ethanol to form the malonate derivative 33.



31 32 33

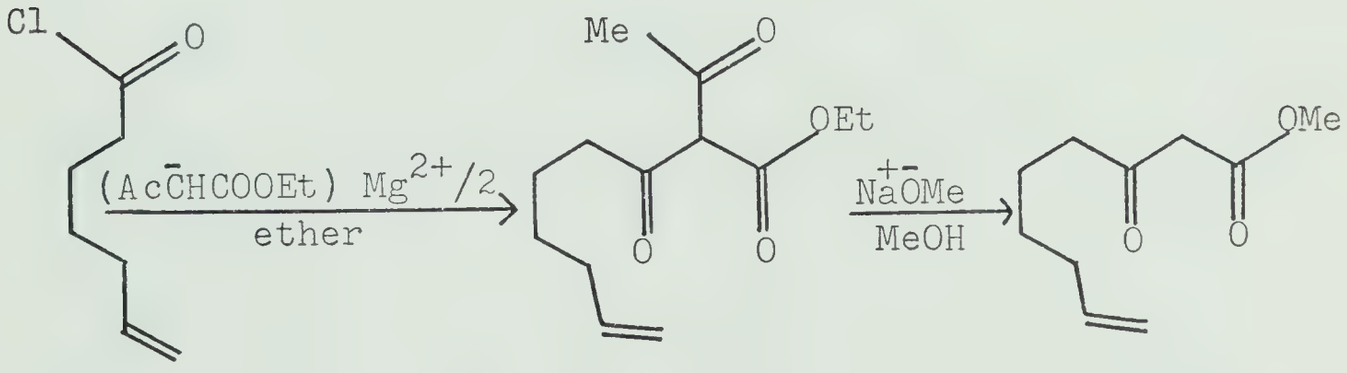
The diester 33 was saponified by treatment with sodium hydroxide in 90% aqueous ethanol to yield the diacid. Decarboxylation gave heptenoic acid (34) which was treated with thionyl chloride to form the acyl

chloride 35.



33 34 35

The acyl chloride was condensed with the magnesio derivative of ethyl acetoacetate in ether to give 36. Cleavage of the acetyl group by treatment with sodium methoxide in methanol gave the β-ketoester 37.



35 36 37

Reduction of 37 by reaction with lithium aluminum hydride in tetrahydrofuran produced 7,9-dihydroxy-1-nonene (38). The mass spectrum showed the molecular ion at m/e 156, which is correct for $C_9H_{18}O_2$. The nuclear magnetic resonance (nmr) spectrum* showed the

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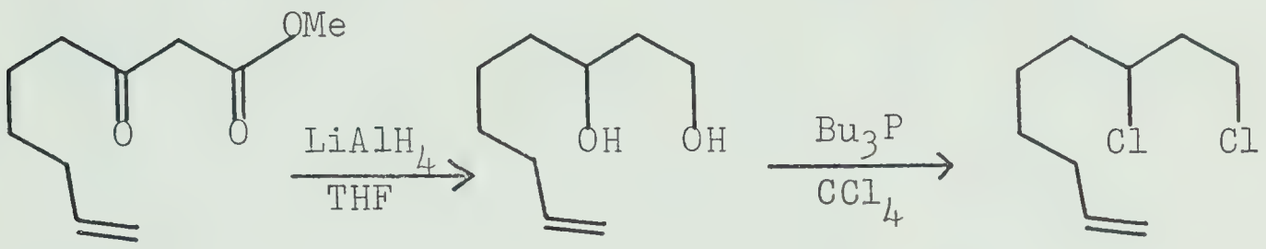
* The nmr data are assembled in Table III.

two hydroxylic protons, the three vinyl protons and the two allylic protons. The three protons on C_7 and C_9 appeared as a triplet centered at τ6.2, and the remaining eight protons were represented as a complex absorption in the methylene region.

Diol 38 was converted to 7,9-dichloro-1-nonene (39) by reaction with tributylphosphine in carbon tetrachloride.



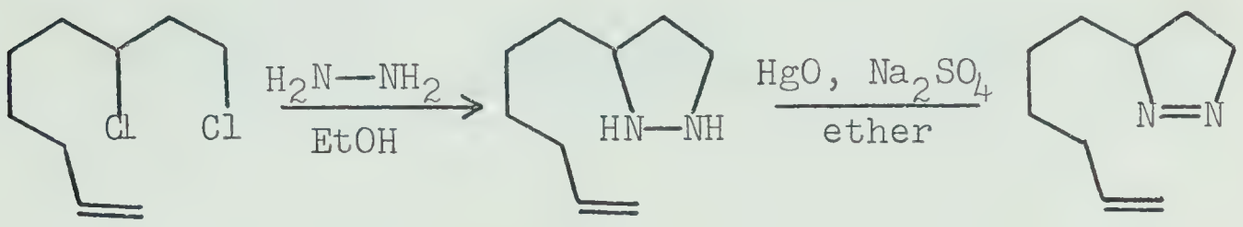
37 38 39

The mass spectrum of 39 showed the molecular ion triplet with peaks at 194, 196, and 198 of relative intensity 9:6:1, as expected for the empirical formula $C_9H_{16}Cl_2$. The nmr spectrum again showed the three vinyl protons. The allyl protons overlapped the C_8 methylene, appearing between τ7.7 and 8.1. The C_7 proton appeared as a multiplet at 5.9, and the C_9 methylene as a triplet at 6.3. The remaining six protons showed a complex absorption in the methylene region.

The pyrazolidine 40 was produced by treatment of 39 with hydrazine in ethanol. The nmr spectrum showed the vinyl protons in the same position, the allyl protons at

τ7.35, the C_7 proton at 6.7, the C_9 methylene at 6.2, the C_8 methylene at 7.9 and a complex absorption for the remaining six protons centered at 8.4

Oxidation of 40 by mercuric oxide in ether yielded the pyrazoline 29. High resolution mass spectrometry

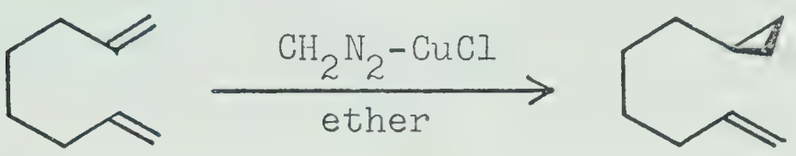


39 40 29

showed the exact mass as 152.1311, which agreed with the calculated value 152.13134 for $C_9H_{16}N_2$. In the nmr spectrum the vinyl and allyl protons are visible, the C_7 and C_9 protons appear as a multiplet between τ5.8 and 6.7, and the remaining eight protons appear as a complex absorption in the methylene region. The infrared shows azo absorption (1545 cm^{-1}), with no absorption above 3100 cm^{-1}, i.e. no N—H. The terminal vinyl group is confirmed by absorption at 990 and 905 cm^{-1} and by olefinic (C=C) absorption at 1635 cm^{-1} and olefinic C—H absorption at 3075 cm^{-1}.

Authentic samples of the anticipated major products from the thermal decomposition of 29 were prepared. The cuprous chloride-catalyzed reaction of

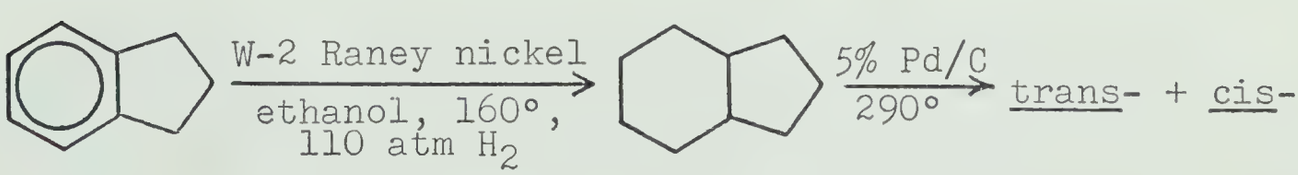
diazomethane with 1,7-octadiene was employed to prepare a sample of 6-cyclopropyl-1-hexene (41). The identification of a purified sample was verified by nmr spectroscopy. The usual vinyl absorption appeared, as well as the allyl methylene at τ7.95 and the five cyclopro-



41

pyl protons, three at 9.5 and two at 10.0. The remaining six protons appeared as the familiar complex absorption in the methylene region of the spectrum.

Reduction of indane in ethanol by W-2 Raney nickel at high temperature and high pressure produced a sample of perhydroindane. The cis-isomer was almost the exclusive product. Complete saturation was confirmed by nmr spectroscopy of a purified sample, which showed only alkyl absorption. This was heated with palladium on carbon to give an equilibrated mixture of trans-perhydro-

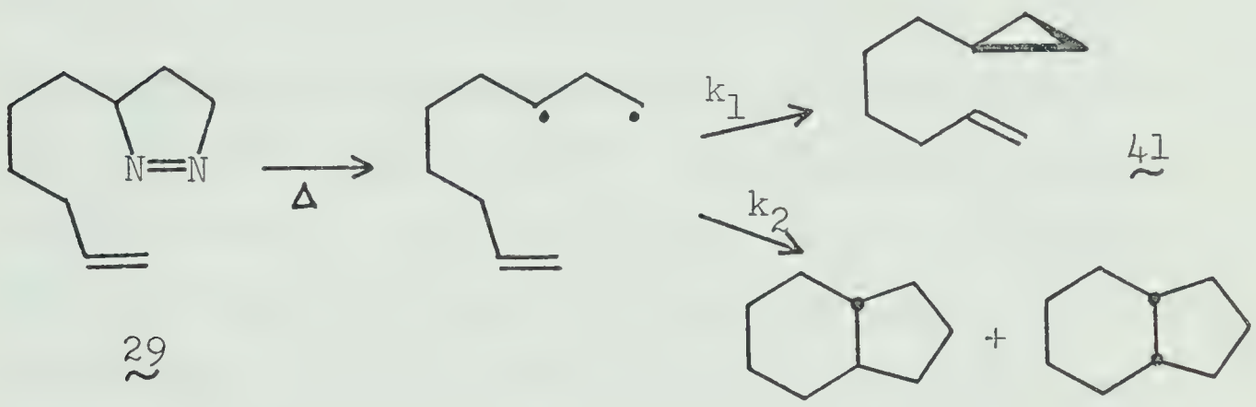


42 43

indane (42) and cis-perhydroindane (43) along with some indane, all of which were identified by comparison of their mass spectra (Figure 7) with the published spectra (29).

(B) Trapping Experiment

In preparation for the decomposition study of 29, a mixture of authentic samples of the expected products from direct closure of the diradical intermediate to a cyclopropane derivative and trapping of the intermediate by the olefinic bond (Scheme III) was analyzed on two different analytical gc columns.



29 41 42 43

Scheme III

Tables IV and V show the relative retention times of 41, 42 and 43, determined on a 150' x 0.01" SE-30 column and on a 150' x 0.01" β,β'-Oxidipropionitrile column, respectively. Table VI shows an analysis of the mixture for relative amounts of the components, and

the precision that was obtained in the analysis.

The pyrazoline was not readily eluted through either column.

A 10 μl (approximately 50 μmole) sample of 29 in a sealed tube was pyrolyzed for 30 min at 200.5°, initial pressure about 100 torr. The time was judged to be between one and two half-lives [for 3-methyl-1-pyrazoline, $t_{1/2}$ = 17.4 min at 203.1° (1)].

The sample was cooled rapidly and was held at 0° while analyses were carried out. Tables VII and VIII show the results of analyses on SE-30 and on β,β'-Oxidipropionitrile columns, respectively. Comparison of Table VIII with Table V shows nothing in the sample which matches the retention time of cis-perhydroindane and only a minor peak (0.02%) corresponding to trans-perhydroindane. Comparison of Tables VII and IV shows that the sample contained nothing corresponding to either trans- or cis-perhydroindane, within the limit of detection.

Table VII

Analysis of the thermolysis products from 3-(5'-hexenyl)-1-pyrazoline (29) on SE-30

Column: 150' x 0.01" SE-30; helium pressure, 20#/in^2; temperature 60°

Mean Retention Time (Min)	Relative Retention Time	Mean Proportion (%)	Standard Deviation
5.95	0.56	0.01	
6.11	0.57	0.02	
8.82	0.83	2.35	0.024
9.33	0.88	0.04	0.006
9.51	0.89	1.01	0.020
9.93	0.93	1.11	0.015
10.63	1.000	91.44	0.353
11.06	1.04	4.01	0.401

Table VIII

Analysis of the thermolysis products from 3-(5'-hexenyl)-1-pyrazoline (29) on β,β'-Oxidipropionitrile

Column: 150' x 0.01" β,β'-Oxidipropionitrile; helium pressure 20#/in^2, temperature 40°

Mean Retention Time (Min)	Relative Retention Time	Proportion (%)
3.74	0.40	0.02
5.51	0.59	0.01
6.46	0.70	0.04
7.36	0.79	3.40
7.76	0.84	2.24
8.24	0.89	1.12
9.26	1.000	93.14
9.61	1.04	0.02

CONCLUSIONS

The analysis of the products from the thermal decomposition of 3-(5'-hexenyl)-1-pyrazoline (29) shows that no perhydroindane was produced within the limit of detection. At the same time, the analysis gives a reliable result for one component which is present in the amount of one part in 10,000. Thus it may be concluded that the rate constant k_1 for closure of the intermediate to a cyclopropane is greater by at least four orders of magnitude than the rate constant k_2 for the trapping reaction (Scheme III).

If we take the rates k_1/k_2 as 10^4, we can calculate the minimum difference in free energy for the two reactions:

$\Delta\Delta G^{\ddagger} = RT \ln k_1/k_2$

$R = 1.987$ kcal mole^{-1} deg^{-1}

$T = 473.7°$

$k_1/k_2 = 10^4$

$\Delta\Delta G^{\ddagger} = (1.987)(473.7)(2.303)(4)$ kcal mole^{-1}

$= 8.6$ kcal mole^{-1}

Benson (30) has suggested that the trimethylene intermediate in the isomerization of cyclopropane to propylene lies in an energy well of approximately 7.3 kcal mole^{-1}. If the intermediate from decomposition of

~~29~~ is a similar species in a well of similar depth, then the free energy barrier for the trapping reaction must be 15.9 kcal $mole^{-1}$ or greater.

We must conclude that if the intermediate is the proposed trimethylene species, then a more effective scheme is required to trap it.

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